the commonly accepted value, 0.862 gm./cm.[3], partly no doubt on account of the low temperature of the crystals, and partly perhaps because the values usually quoted have been obtained for metal not perfectly crystalline, to judge by the X-ray evidence. As regards the purity of the potassium here used, it can only be stated that the original material was purchased as "c. p." from Eimer and Amend, was dried and freed from the usual oily surface layer, and was then melted and double-distilled in vacuo using only pyrex glass. The samples were prepared for me under the supervision of Dr. H. E. Ives from material used by him in the preparation of photoelectric cells. His suggestion that a change in the crystalline condition of the metal at low temperatures might be responsible for certain anomalies in photoelectric emission was the starting point of this research.

The observed crystalline structure does not persist when the temperature is allowed to rise again to about 20° C. No effort has been made to determine the highest temperature at which crystallinity can still be detected, since it seems probable that the loss of structural symmetry is not abrupt but gradual.

[1] A. W. Hull, *Physic. Rev.*, (2) **10,** 661–696 (Dec., 1917).

[2] L. W. McKeehan and P. P. Cioffi, *Ibid.*, (2) **19,** 444–446 (April, 1922).

PRELIMINARY REPORT ON THE IONIZATION OF POTASSIUM VAPOR BY LIGHT

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As Hughes states in a *Bulletin* of the National Research Council,[1] experimental results relative to the ionization of metallic vapors by light, have been very meagre, and it is difficult to point to any phenomena which are due, without doubt, to ionization by radiation of optical frequencies. Steubing[2] describes ionization of mercury vapor by light transmitted through fused quartz, but his results seem probably to be explained as ionization in the vapor by collision of photoelectrons from the electrodes. Anderson[3] and Gilbreath[4] have published results obtained in potassium vapor which seem to be due to wall emission. Kunz and Williams,[5] in a brief abstract, state that while caesium was not ionized by radiation of wave-lengths greater than 3130 Å, a marked effect was secured at 2530 Å. No details as to the method have as yet come to the writer's notice.

The equation $Ve = h\nu$, where V is the voltage corresponding to the

energy of the electron, e the electronic charge, h the quantum constant, and ν the frequency of radiation, finds application in the field of X-rays, either in calculating the maximum frequency of radiation excited in solids by electrons having energy corresponding to the voltage V, or, conversely, in computing the maximum energy of the secondary electrons liberated from solids by radiation of frequency ν.

Work in the metallic vapors indicates that in the case of the alkaline metals the principal series of doublets is radiated when ionization of the vapor by electronic collision occurs, and the limiting frequency of the series is given by the substitution of the ionizing potential in the above equation. Conversely, when it is desired to ionize a vapor by radiation, thus liberating electrons, it is natural to assume that frequencies must be employed which are equal to, or greater than, the above limiting frequency calculated from the ionizing potential. The results of Kunz and Williams in caesium vapor are at least in accordance with this view. In the case of potassium vapor, the observed ionizing potential is 4.1 volts[6] and the corresponding principal series limit is 2856 Å.[7]

The experiments here described were planned to verify the ionization of metallic vapor by radiation of optical frequencies and to investigate the ionizing power of the radiation as a function of the frequency. The following considerations must be borne in mind in determining the method:

(*a*) Thermelectrons are emitted quite freely by glass and metals in the presence of potassium vapor at temperatures as low as 150°. Also such surfaces in the presence of potassium vapor, or when covered with solid potassium, may give a marked photoelectric emission if there is any scattered light. The procedure must then be arranged so that currents consisting of positive ions, due to ionization, can be distinguished from these electronic currents.

(*b*) Absorption of the radiation by the vapor should be limited, if possible, to the region between the electrodes.

(*c*) Where accelerating fields are used, ionization by collision of electrons with the vapor may occur, and such an effect must be distinguished from ionization by radiation.

Therefore, the following method was adopted. A jet of hot potassium vapor was directed into a cool vacuum chamber and condensed upon the walls, a part of the latter being cooled by means of liquid air. A carefully diaphragmed pencil of light traversed this jet a short distance from the nozzle and then entered a conical glass tube serving as a light trap. A mercury arc in quartz was used as the source of radiation, and absorbing screens could be interposed between the arc and the vacuum chamber. Electrodes were so arranged that the positive ions formed in the jet could be accelerated through a gauze to travel against a suitable retarding field (V_r) to an electrode connected with an electrometer. The energy gained

by the positive ions was not due to the full applied accelerating voltage (V_a), since they started from a somewhat extended region between the electrodes. A sliding shutter over the vapor nozzle made it possible to cut off the vapor jet.

Holding the retarding potential constant and varying the accelerating field, observations were made and a curve plotted showing current to the electrometer versus accelerating voltage, when the jet was illuminated

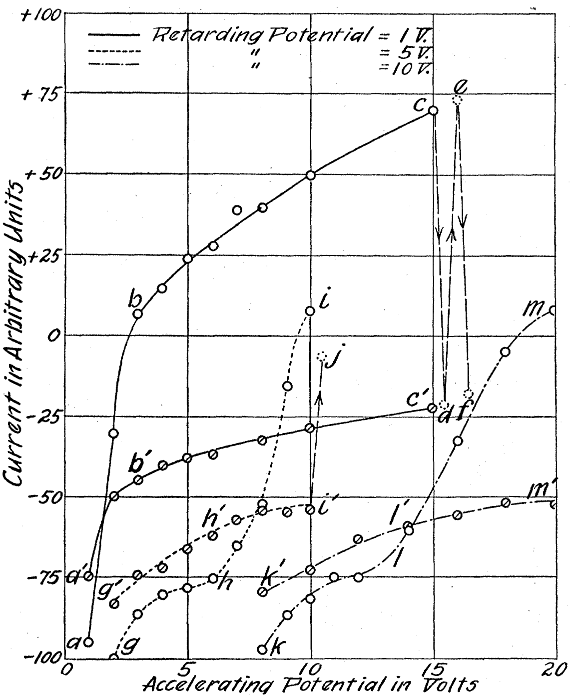

FIG. 1

abc, ghi, klm, were taken with radiation unscreened, minimum wave-length about 1850 Å.; *a'b'c', g'h'i', k'l'm'* were taken with screen, minimum wave-length about 3100 Å. *I'j* gives change when screen is removed. *cd-de* is the change when vapor jet shutter is closed and reopened, and *ef* is due to inserting screen.

by unscreened radiation from the arc. This procedure was repeated with a screen interposed which cut out quite sharply wave-lengths less than 3100 Å. Pairs of such curves were obtained for retarding potentials of 1, 5, and 10 volts, as shown in figure 1.

The curves taken with the radiation unscreened show negative currents with marked breaks toward positive values at accelerating voltages which depend upon the retarding potentials. The negative currents are due to

photoelectric leak from the gauze and walls, which was unavoidable, and also at the lower accelerating voltages to thermelectrons from the nozzle of the jet. The breaks toward positive values resulted when the positive ions, which were produced in the jet by the radiation, acquired sufficient energy in the accelerating field to enable them to reach the electrometer electrode against the retarding potential. When a screen was inserted to cut out wave-lengths less than 3100 Å, the negative leak was reduced by a small amount, while the positive breaks disappeared, showing that the positive currents depend upon the presence of wave-lengths which are less than 3100 Å. It may be suggested that the positive current is due to

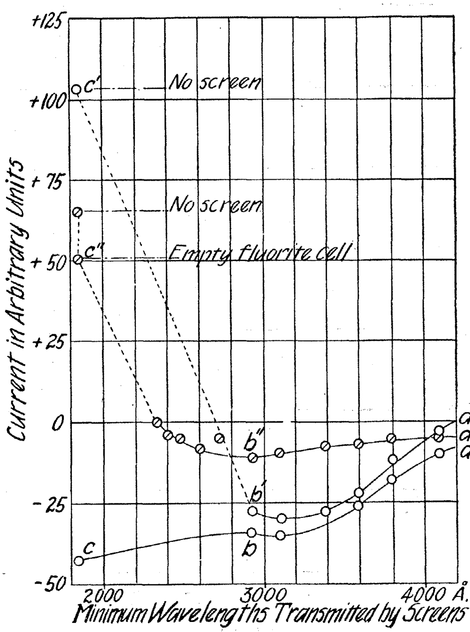

FIG. 2

ionization in the jet by collision of photoelectrons from the gauze, and that the disappearance of that current upon screening out wave-lengths below 3100 Å results from the correspondingly lower initial energy of emission of these photoelectrons. The electrons reach the jet of vapor with their initial emission energy plus at least ½ V_a. Therefore, even though the initial energy were zero in the screened curves, we should have positive ionization by collision when V_a is greater than about 8.2 volts or twice the ionizing potential. And the pairs of curves for V_r greater than 4.1 volts, would show no marked decrease of ionization with screening. On the contrary, the pairs of curves are of the same type for retarding potentials of from 1 to 10 volts, and there is no indication in the screened curves

of ionization by collision for the higher accelerating potentials. Hence we may conclude that the positive ionization is due to radiation between 3100 Å and about 1850 Å (probably the shortest wave-lengths present in the arc spectrum), and also that under the conditions of the experiment ionization by collision was of a lower order of magnitude than that due to radiation.

If the vapor jet is cut off by means of the shutter under conditions as shown in figure 1, approximately the same effect is produced on the current as by inserting the screen in the path of the light. This confirms the view that the negative residual current is due to photoelectric leak, and, furthermore, indicates that the scattered light which produces this leak comes largely from the diaphragming system and is not due to any marked scattering or resonance by the vapor.

In preliminary tests of the ionizing power of the mercury arc spectrum, as a function of wave-length, the retarding and accelerating potentials were set at one and ten volts respectively. Absorbing screens were successively inserted in the beam of radiation, and the observed currents were plotted against the lower transmission limits of the screens, figure 2. Curve *abc* represents the effect of the screens on the photoelectric current from surfaces due to stray light, being taken with no vapor present; $a'b'c'$ and $a''b''c''$ were taken with vapor issuing from the nozzle. No screens for the region below 2900 Å were available at the time *abc* and $a'b'c'$ were taken. These curves show a positive current superposed upon a negative photoelectric surface current. This positive current appears at about 2900 Å and increases quite rapidly as the wave-lengths decrease. The ionization does not seem to be associated with resonance phenomena or the absorption of a single wave-length in the vicinity of 2900 Å. Rather it appears to be a continuous function of the wave-length, starting near the convergence wave-length of the principal series and increasing quite rapidly as the wave-length decreases, giving a continuous absorption of energy below this limit. It is of interest to note, in this connection, the region of continuous absorption described by Wood[8] in the case of sodium vapor which extends from the convergence frequency of the principal doublet series on down in the ultra-violet, thus corresponding with the region of ionization and consequent absorption of radiation observed for potassium.

The above results can be summarized as follows:

It is believed that definite evidence has been obtained of the ionization of metallic vapors by light.

The results indicate that there is a long-wave limit in the case of this ionization which can be calculated from the relation $Ve = h\nu$ by means of the ionizing potential.

The ionizing power of the radiation is a continuous function of the wave-length below this limit, increasing as the wave-length decreases.

The investigation will be continued with the idea of extending the observations to other elements and, also, of getting more accurate measurements of various factors involved.

[1] Hughes, *Bulletin, Nat. Res. Council, Washington,* **2,** 1921 (86).

[2] Steubing, *Physik. Zs.,* **10,** 1909 (787).

[3] Anderson, *Physic. Rev.,* **1,** 1913 (233).

[4] Gilbreath, *Ibid.,* **10,** 1917 (166).

[5] Kunz and Williams, *Ibid.,* **15,** 1920 (550).

[6] Tate & Foote, *Phil. Mag.,* **36,** 1918 (64).

[7] Hughes, *loc. cit.* (168).

[8] Wood, *Phil. Mag.,* **18,** 1909 (531).

THE ABSORPTION OF LIGHT BY SODIUM AND POTASSIUM VAPORS

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The continuous absorption found at the limit of the principal series in sodium and potassium is of great importance on the Bohr theory of atomic structure, corresponding as it does to the ejection of an electron from the atom. It was first noticed by Wood[1] in sodium, who mentioned that it began in his pictures at the last resolved line, and extended to the extreme ultraviolet. Holtsmark[2] studied it in sodium and found it also in potassium though to a less marked degree.

The present work was undertaken to study the relation of the band, line, and continuous absorption in sodium and potassium vapors, to temperature, hydrogen pressure, and vapor saturation. It was thought that some change in absorption might be obtained if the vapor was superheated.

Experimental Arrangements.—The metal was enclosed in iron tubes of 4 cm. diameter and length from 15 to 200 cm., depending upon the type of absorption to be studied. A side arm was welded to the center of the absorption tube, and so arranged that it could be heated separately. Clean sodium was then placed directly in the side arm, and after the main tube had been pumped out and raised to the desired temperature a small quantity of sodium could be distilled into it from the side tube at will. In this way a rough degree of control could be exercised on the saturation of the vapor.

Blast flames were used as a source of heat. The main tube was closed by quartz lenses kept cool with water jackets. To prevent too rapid